TECHNOLOGY PATHWAY PARTNERSHIPS
REFERENCE DOCUMENT

In support of the U.S. Department of Energy
SOLAR AMERICA INITIATIVE

MATERIAL PERTAINING TO:
FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

SAI Technology Pathway Partnerships Phase 1

Opportunity Number: DE-PS36-06GO96034

Announcement Type: Initial

CFDA Number: 81.087

1.0 Introduction:

This document provides further information to prospective Applicants under the U.S. Department of Energy Financial Assistance Funding Opportunity Announcement (FOA) for SAI Technology Pathway Partnerships Phase 1, FA Opp Number DE-PS36-06GO96034.

The information contained herein is intended to aid Applicants as they complete their applications by:

- Explaining the context and processes by which projects will be managed and tracked from the perspective of the DOE Solar Energy Technologies Program (SETP).
- Expanding upon some of the requirements stated in the FOA document.
- Discussing the use and management of data obtained during the execution of the Solar America Initiative (SAI).

The primary purpose of this document is to convey information to Applicants that will be of use in the development of applications under this FOA. A secondary purpose is to provide a contextual basis for the requirements stated in the FOA, with the intention of facilitating the development of clear, concise applications that directly address DOE program goals.

The Solar Energy Technologies Program will implement the SAI using the Systems-Driven Approach (SDA) to program management, which the Program has tailored to solar applications over the past three years. SDA processes use empirical data to assess the relative marketplace impacts of different research and development directions. With SDA, researchers have a common basis to communicate the value of their work and understand how it fits directly into overall program goals. This applies throughout the PV product development cycle, from fundamental research on materials and devices to improved components and integrated PV systems. Thus, the Stage Gate methodology, the modeling and analysis work, and the collection of sound data through testing and evaluation – all explained in this document – are interconnected efforts employed as part of the Systems-Driven Approach.

The content of this document is as follows. Section 2 is a discussion of the Stage-Gate methodology of program management and technology development, and its application to SAI. Section 3 discusses the modeling methods that DOE will use to determine the levelized cost of energy (LCOE) for current and proposed PV systems. Section 4 discusses the roles of DOE and other laboratories in test and evaluation of hardware throughout the SAI process, with particular emphasis on what's needed in an application. Section 5 closes with a brief conclusion.

2.0 Stage Gate Management in the Solar America Initiative

2.1 Overview of Stage Gate program management

The Stage Gate process is a means of making focused, goal-oriented disciplined research and development decisions at all stages along a product development cycle. The Stage Gate process is being used throughout the Solar Energy Technology Program (SETP). A schematic of the Stage Gate process currently being used in the Photovoltaic R&D activities in the solar energy program is shown in Figure 1.

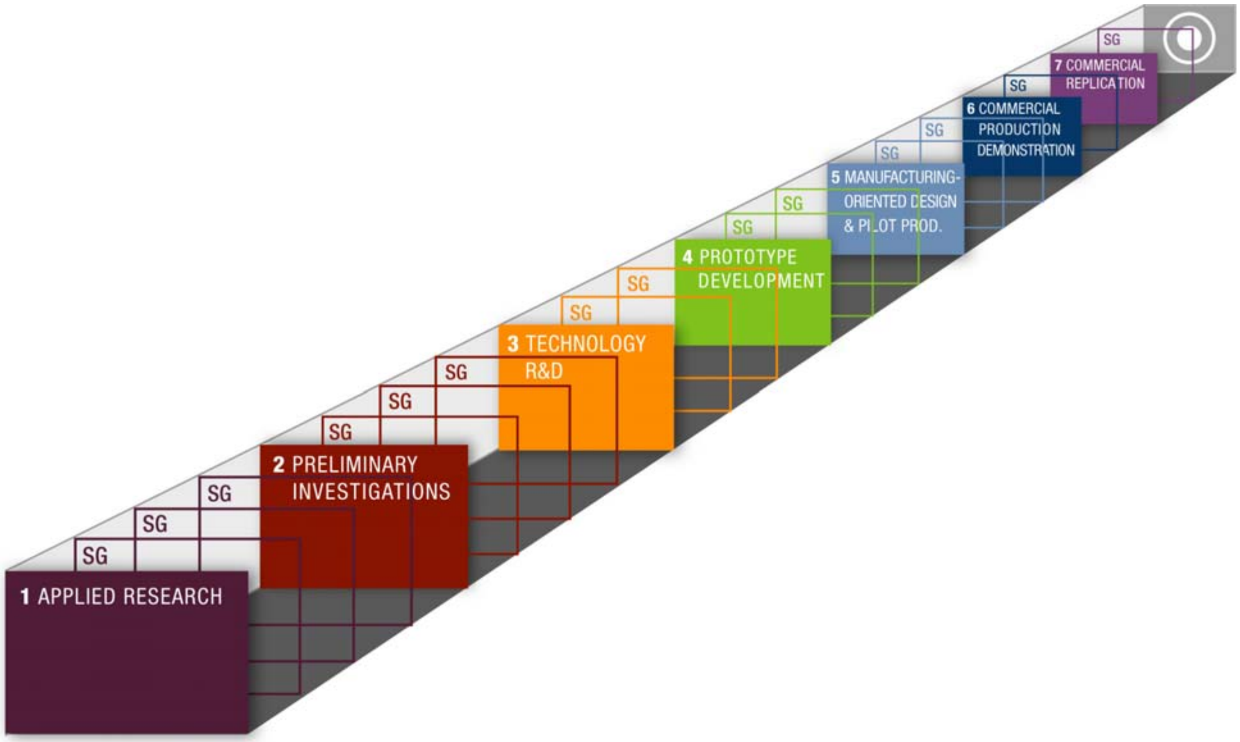

Figure 1 – Stage Gate Schematic for Photovoltaics R&D

The basic approach[1] is as follows: project development takes place in a series of sequential "stages" and the reviews of the projects are done at "gates". The "development cycle" for a project can go from applied research investigations through technical activities that support high-volume production. Increasing rigor, industry involvement, and investment level are expected as development moves through successive stages. This approach is applied across varying levels of development and integration of new PV systems, from new subcomponents to fully integrated systems.

Implementation of the Stage Gate process will allow the SETP to continuously evaluate several principal areas of R&D portfolio management:

- Strategic Alignment – Ensures R&D activities are directly aligned with the overall goals and strategy of the solar program.
- High Value – Positions R&D portfolio to make the largest potential impact on the solar energy industry.
- Balance – Ensures technical activities that produce cost, reliability, and performance improvements in all important areas of PV systems development.

[1] The stage gate process was originally proposed by Cooper as a model for product development projects and has been extensively modified. See: Cooper, .R.G., Winning at New Products: Accelerating the Process from Idea to Launch", 2nd Edition. 1993, New York: Addison-Wesley Publishing Co.

- Accountability and Transparency – Allows program to establish accountability for progress in meeting quantified, integrated goals, which can be readily seen and assessed by stakeholders.

These points are particularly relevant and important because of the use of the Stage Gate process as an integral component of an improved SETP management approach that takes a systems perspective (the Systems Driven Approach). As TPP projects are implemented, the DOE will use Stage Gate Reviews to assess the utility of continued project funding, with respect to current and future market considerations, quantification of the impact of technical improvement opportunities, and prioritization of program activities.

2.2 Stage Gate Program management in SAI

The Stage Gate process has been adapted for use in evaluating the progress of Technology Pathway Partnerships in the SAI. In more conventional stage-gate application, the final gate is reached when the product is "launched" or the process implemented in a production line. For the SAI, the Stage Gate process has been extended to include technical support of commercialization activities until the time (anticipated to be by 2015) when the PV industry achieves SETP cost goals and is producing products at high volume. At each gate, the maturity of the proposed products, the manufacturing process and capacity, and the efficacy of the commercialization plan will be assessed.

For the SAI, the SETP has defined stages, described below, to provide a consistent framework for applications and evaluation of progress. Applicants must define gates, associated criteria, deliverables, timing, and must state how they will demonstrate satisfaction of criteria. In this way, DOE will provide the structure (i.e. stage definitions) for the TPP applications without over-prescribing or over-constraining the Applicants. Where Applicants' projects do not fit easily into the linear product development cycle defined in the SETP stage definitions, they may propose in their application an alternate set of stage definitions and associated stage gates.

The activities of the partners within a TPP will not be expected to be at the same stage in the development cycle during Phase 1 of SAI. For example, the development of a large-scale, high-speed module manufacturing process may be at a different stage of development than that of an inverter that is planned as part of the overall PV system proposed by a TPP. In their applications, Applicants will show these distinct staged development pathways for their technologies, providing gate criteria and milestones for each individual path. Applicants will also show the ultimate convergence of these pathways into the development of new PV systems or components.

The DOE also recognizes that some TPP's may actually conduct multiple iterations through certain stages for a given component, system, or production process – during their Phase 1 project alone, or over the course of their 9-year R&D and technical plan. This approach is entirely acceptable, and should be employed by the applicant where it provides opportunity for market deployment of reduced-cost systems or components. The applicant should describe these aspects of their approach in the Statement of Objectives and Technical Approach/Project Management sections of their application.

Figure 2 is a representative TPP project schedule, illustrating parallel development pathways for PV components could be integrated into a PV system during the execution of an example TPP Phase 1 Project. Stage gate reviews are included at approximately one-year intervals, and associated test & evaluation activities are integrated as well. The stage definitions in Figure 2 apply to the level of development for the PV system as a whole, while development activities related to different components will likely be at distinct stages prior to integration into the system. In this case, Applicants must define the relative stages for each technical pathway proposed, and show the timeframe for how these will be integrated into new, improved PV systems under SAI.

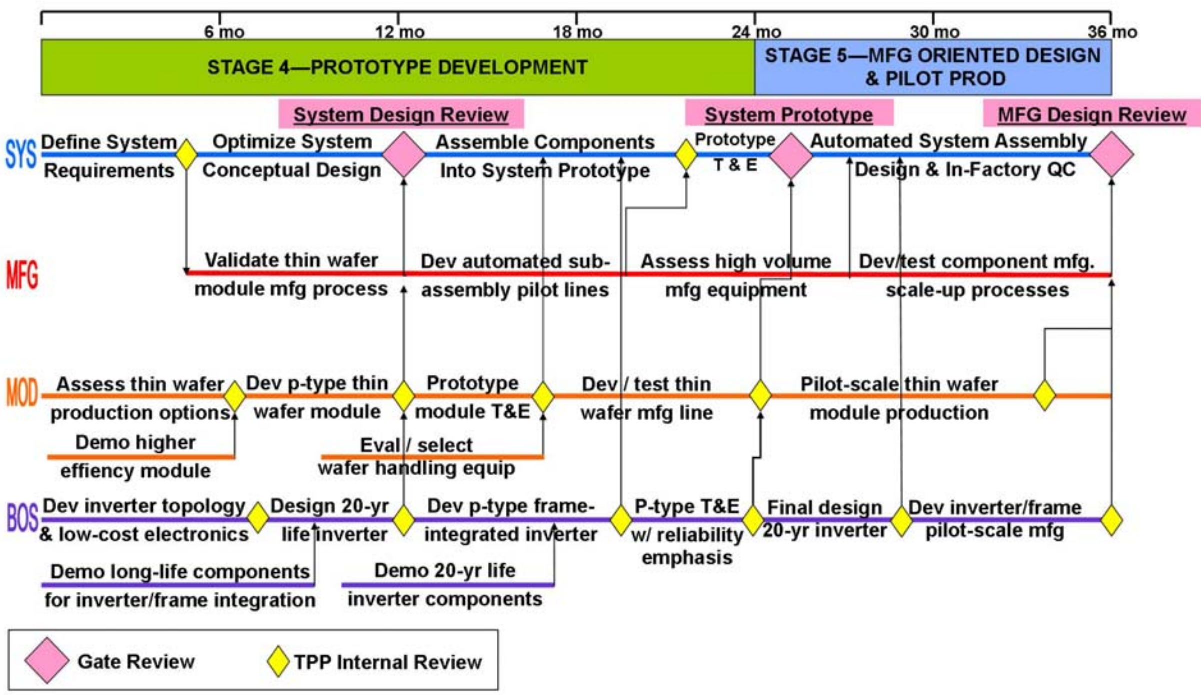

Figure 2: Sample TPP development schedule, showing integration of parallel activities into overall PV system and associated stage gate reviews.

2.3 Stage Definitions

Within the PV program, the DOE has identified 7 stages in the development cycle. These stages are shown in Figure 1. Discussions of these stages are provided below to facilitate the formulation of applications. Stages 1 and 2 are included here for completeness, while TPPs are expected to conduct the majority of their activities in Stage 3 or higher.

Stage 1: Applied Research. The start of this stage is where the transition from basic science research occurs, and can include such activities as identifying and exploring promising materials that enhance performance of existing technologies and establish feasibility of new processes. A reasonable expectation of commercial success can be based on such things as low raw material costs, higher efficiency potential, efficient manufacturing processes, chemical stability, extended lifetimes, etc.

Stage 2: Preliminary Investigations. This stage involves initial technical and market assessments of product or process technology concepts, using a combination of laboratory investigations, physics-based modeling, parametric estimation, or other relevant analytical methods. Focus is on preliminary science investigations or literature review without component or system prototype development. Lab-scale device prototypes are developed and preliminary stability tests are made.

Stage 3: Technology Research and Development. This stage includes the development of PV system or component prototype designs with full functionality and complete "look and feel" of commercial product. Prototypes are developed often using devices produced in pilot-scale operations; accelerated-life and qualification tests are used to improve component design and gain early insight into reliability issues. Proof-of-concept is completed for all new manufacturing processes. Lab tests provide data for system integration and optimization.

Stage 4: Prototype Development. Development and demonstration of integrated (full-scale) prototypes in a relevant operational environment are conducted in Stage 4. Performance measurements and cost evaluations (often produced in pilot-scale operations) support prototype development, including use of accelerated lifetime and stress testing to improve reliability and mitigate potential field problems. Refinements to the commercialization plan are then based on prototype system development and manufacturing process demonstration results.

Stage 5: Manufacturing-Oriented Design and Pilot Production. Pilot-scale production of fully-engineered products is the goal of this stage. This includes completion of all associated lab and field tests to assure stated performance and reliability. Development of pilot-scale facilities to prove manufacturability, Quality Control, and demonstrate readiness for commercial scale-up should be accomplished.

Stage 6: Commercial Production Demonstration. In Stage 6, the establishment of full-scale production facilities, and initiation of full-scale production at increments of approximately 25MW annual capacity is expected. Completion of new round of lab/field verification on all critical features to assure QC at high production rates will also be pursued.

Stage 7: Commercial Replication. Graduation from the SAI initiative occurs at the end of this stage. This includes technical improvements through feedback from earlier production and tests; further lab and field testing/monitoring of overall QC of massive manufacturing process. Continued quantification of product reliability evaluations based on extensive customer usage are included in this last stage.

2.4 Gate Reviews

Gate reviews are an extremely important aspect of the Solar America Initiative. SETP staff will use information gained during these reviews to make informed decisions regarding the strategic direction of SAI in general and, more specifically, regarding the future of individual TPPs. Applicants are required to provide sufficient information in their respective applications that indicates the types of data, deliverables, testing, evaluation, and reports that will be developed and made available for gate reviews. A schematic of the review process provided in Figure 3.

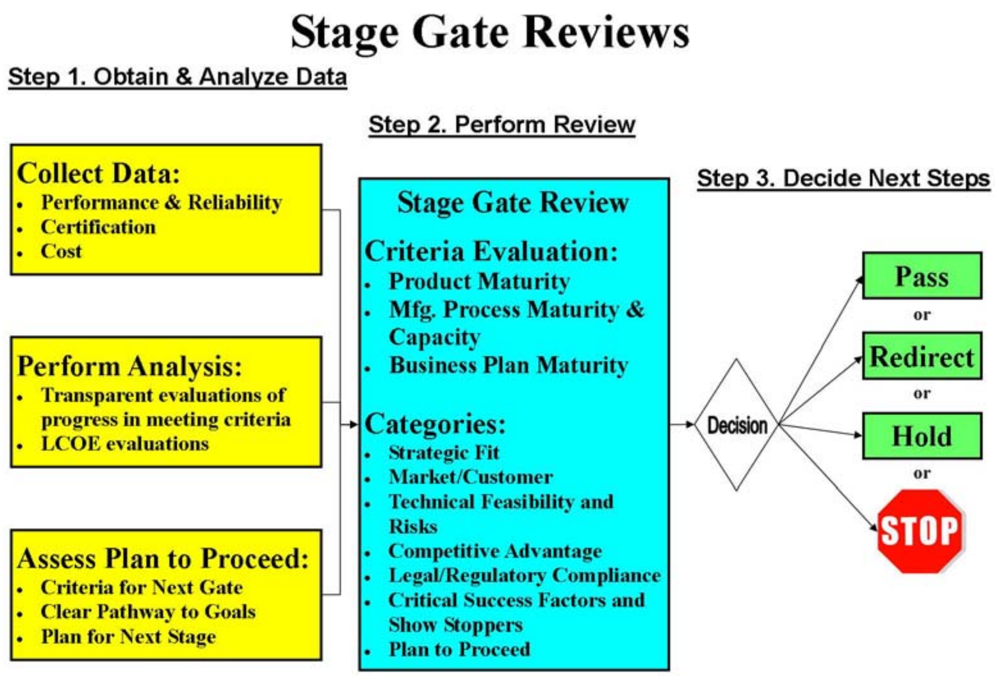

Figure 3 – Stage Gate Review Process

Four decisions are possible as outcomes from a gate review: Pass (to the next stage), Recycle/Redirect (stay in the same stage but complete additional necessary work), Hold (suspend DOE support for the project until additional data supports restarting or canceling), or Stop (no further DOE support for this project). At each of these major gates, deliverables must be provided as specified in the TPP-developed project plans. These deliverables will be independently evaluated to assure that they are sufficient to demonstrate that the criteria (previously specified by the TPP) have been met. Results from SETP test and evaluation activities, described later in this document, will be used as input for gate reviews as well. The deliverables must include a detailed plan (including specific criteria for subsequent gates) for activities proposed in the next stage of activity.

These gate reviews are not status reports. Each TPP must identify at least 3 major gate reviews (approximately annually) in the planning of Phase 1 activities in the SAI. Criteria for each of the stage gates must be "SMART": Specific, Measurable, Achievable, Relevant, and Timely.

2.5 Data management and associated protocols

The SETP will develop protocols to assure comprehensive management of information generated and collected throughout SAI in collaboration with all TPPs, the Golden Field Office, and supporting National Laboratories. This includes:

- Establishing data baselines as input to the Solar Advisor Model and other models.
- Reporting of non-proprietary data under the SAI initiative.
- Storage and manipulation of data within SAI and SETP.
- Protection of proprietary data, as required by SAI cooperative agreements.
- Tracking of deliverables, including reports and hardware submissions.

SETP needs access to recipient data under the SAI cooperative agreements, both to measure progress under individual agreements and to report overall SETP progress. For the latter purpose, data will be aggregated to protect proprietary information as necessary.

2.6 Roles and responsibilities in the stage gate process

Specific roles and responsibilities of Applicants and subsequent Recipients related to Stage Gate management are listed below:

- **TPP Application**
  - Develop and submit TPP application stage gate review criteria, identify review items/deliverables, and provide schedule.
  - Identify SETP technical support activities needed to both verify gate completion and to support TPP product development activities.
- **Plan Gate Review Meeting**
  - Support gate review agenda development.
  - Provide background information (criteria, deliverables, and milestones, etc.) to Technical POC for distribution to reviewers.
  - Plan and dry run gate review presentations.
- **Gate Review Meeting**
  - Present accomplishments from current stage(s) clearly describing progress compared to the plan including goals, deliverables, and milestones; address all gate criteria and their relationship to meeting program goals.
  - Present plan for next stage including major goals, deliverables, and milestones as well as preliminary schedule and budget.
  - Respond to all gate keeper questions or issues.
- **After Gate Review Meeting**
  - Assess and respond, as directed by Project Monitor, to review guidance.
- **Proceed with Project**
  - Develop detailed project plan covering all activities leading to next review.
  - Review detailed plan with Project Monitor and submit for approval.
  - Execute and manage the project.

The SETP roles in applying the Stage Gate Process to the Solar America Initiative are principally related to program management, project monitoring, and technical support. In program management, DOE will establish the strategic context for project selection and review, participate in stage gate reviews, review detailed project plans, and asses project status. Each TPP will be monitored by a team of appropriate experts with a team lead, who will serve as the TPP's primary point of contact. The point of contact will be the principal point of contact for TPPs on technical issues, will lead gate reviews, and will assure that TPP schedules are fully integrated with other SETP activities, particularly support activities such as in Test and Evaluation. Technical support activities include all modeling, analysis, test, and evaluation that seek to quantify progress toward meeting program goals.

3.0 Modeling

3.1 Solar Advisor Model

The SETP is using Levelized Cost of Energy (LCOE) as its primary metric for measuring progress towards achieving market competitiveness. A DOE/NREL/Sandia team has developed the Solar Advisor Model (SAM) to provide a common platform for calculating LCOE and to conduct Technology Improvement Opportunities (TIO) sensitivity studies on overall system LCOE. All TPP Applicants are required to use SAM to calculate LCOE in their applications, and award recipients will be required to use SAM to document progress. Applicants must provide clear, credible information supporting their cost and performance inputs to SAM. **Other models or tools, such as existing proprietary industry models, may be used to develop supporting data.**

The Levelized Cost methodology considers the total cost of ownership for a system over its lifetime and divides that number by the total energy produced by the system over its lifetime for a given location, all within a present value calculation. Thus, LCOE includes everything that becomes part of the cost of energy for the electricity customer, including, but not limited to:

- Component performance and system output in kWh's as a function of specified meteorological conditions.
- Expected solar input and other weather conditions (e.g. TMY2 data)
- Time-dependent degradation of plant output.
- Installed-system price, including hardware, design, installation, permits, inspections. Price means costs with profit and all other expenses, such as overhead, marketing, etc. [2]
- Financing including tax impacts (for 2015, only existing, permanent tax measures apply). Incentives such as investment tax credits or production tax credits are not included in the model.
- Cost of ownership, such as operation and maintenance, including related costs such as site maintenance for a ground-mounted system; PV system insurance and property taxes[3]; monthly metering and/or interconnect charges; depreciation, income tax (for systems selling electricity), etc.

As presently configured, SAM calculates performance, cash flow, LCOE, and other results from high-level system price and performance metrics, TMY2 data, and financial parameters. Currently, SAM includes a choice of two module performance sub-models: a single-point efficiency calculation that includes temperature correction, and a more recent empirical Sandia module performance model (see SAND2004-3535), which is used in PV-DesignPro. The financial calculations are derived from *A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies* (NREL Publication TP-462-5173). SAM has a graphical-user-interface that permits input of data and display of results. Results can also be exported as an EXCEL spreadsheet.

[2] Technology pathway partnerships should incorporate all ordinary business expenses which are normally reflected in system or component prices. Because LCOE is calculated based on the installed price of the system to the end user, the margin applied to the direct manufacturing cost of components, and the margin on the full installation cost of the system should be the margin required to sustain a profitable business with a reasonable return on investment in the business' cash flow analysis. The SETP recognizes that actual selling prices will be determined by market conditions.

[3] Cost of PV system insurance and property tax are specified in the financial component of SAM.

SAM is being made available to prospective applicants concurrent with the release of this FOA. Interactive training for use of SAM will be offered via a workshop to be scheduled in July, later via webcast, and via software documentation that will be posted on the SAI website.

SAM is a high-level model and, as such, does not replace the need for detailed modeling and analysis by industry of their own baseline technology data and forecasts. Within the SAI, the primary purpose of SAM is to provide a standard means to calculate LCOE and to provide the capability to conduct parametric studies of the impact of alternative design and development strategies. All applicants must use SAM with Typical Meteorological Year-2 (TMY-2) data for the same location (Phoenix) and SETP-specified financial parameters so that the program may focus its evaluations on critical technology parameters, such as performance and cost, which are inputs to SAM. SAM does not pre-suppose relationships between parameters, such as BOS costs parameterized in terms of \$/module or \$/m^2. However, it does permit users to define relationships between parameters, and permits linking of user-developed Excel spreadsheets that contain detailed calculations. Over time, the capability of the model will be increased in response to the needs of SAI and feedback from SAI teams.

3.2 Solar Advisor Model Input Requirements

Key data inputs to the SAM model include the system location, the system configuration, financial parameters, performance parameters, reliability parameters, and cost parameters. While all variables can be changed, all applicants will be required to include in their application an analysis conducted with the location and financial parameters and location that have been predetermined by DOE.

Location – The standard location for analysis is Phoenix, Arizona (to further illustrate the value of their technology, applicants also have the option of conducting analysis for other locations supported by SAM, i.e. any TMY2 location in the US.)

Financial Parameters – The DOE has identified the following target markets for the Solar America Initiative:

- Residential (small systems connected on the retail side of the meter)
- Commercial (medium to large systems connected on the retail side of the meter)
- Utility (medium to large systems connected on the wholesale side of the meter)

Standard financial parameters to be used in analysis for systems in these markets are shown in Table 1 and are included in the SAM model that is being made available concurrent with this FOA.

Applicant-Defined Inputs – Required applicant defined inputs to the SAM model are also listed in Table 1. The specific purpose of each input is described in the documentation for the model and will be reviewed during the training session. Illustrative values for these applicant-defined inputs are shown in Table 1 primarily to illustrate the use of the model. Neither these values nor the values found in the MYPP are to be considered default values acceptable to the Solar Energy Technologies Program. **Applicants must provide their own performance and cost data and predictions and must clearly document the origin of these data. However, sub-system class applicants may employ values in the table for portions of the system that are not the subject of their work.** For example, in an application involving only module R&D, the applicant could use the values given for inverter cost and performance. However, since module design impacts installation and BOS costs, the applicant should develop their own input and rationale for these parameters.

	PROGRAM	Residential	Commercial	Utility	CPV	units
DOE/SETP-defined Inputs	Technology	**PV**	**PV**	**PV**	**PV**	
	Market	**Residential**	**Commercial**	**Central Gen**	**Central Gen**	
	ENVIRONMENT					
	Climate	**Phoenix**	**Phoenix**	**Phoenix**	**Phoenix**	
	Utility Rate - Flat	Nominal value 12 (affects cash flow, but not LCOE)				¢/kWh
	Financials					
	Type of Financing	**Residential Mortgage**	**Commercial Loan**	**IPP Project**	**IPP Project**	
	General					
	Analysis Period	**30**	**30**	**30**	**30**	years
	Inflation Rate	**2.5**	**2.5**	**2.5**	**2.5**	%
	Real Discount Rate	**5.5**	**5.5**	**7.5**	**7.5**	%
	Taxes & Insurance					
	Federal Tax	**28.0**	**35.0**	**35.0**	**35.0**	%/year
	State Tax	**7.0**	**7.0**	**8.0**	**8.0**	%/year
	Property Tax	**0.0**	**0.0**	**0.0**	**0.0**	%/year
	Insurance	**0.0**	**0.0**	**0.0**	**0.0**	%
	Depreciation	**n/a**	**MACRS-Mid-Q**	**MACRS-Mid-Q**	**MACRS-Mid-Q**	
	Loan					
	Loan (Debt) Percent	**100.0**	**50.0**	*Optimize for minimum LCOE*		%
	Loan Term	**30**	**15**	**20**	**20**	years
	Loan Rate	**6.0**	**6.0**	**6.0**	**6.0**	%/year
	Constraining Assumptions					
	PPA Escalation Rate	**n/a**	**n/a**	**0.0**	**0.0**	%
	Target Internal Rate of Return	**n/a**	**n/a**	**15.0**	**15.0**	%
	Target Minimum Debt Service Coverage Ratio	**n/a**	**n/a**	**1.4**	**1.4**	%
	Positive Cash Flow	**n/a**	**n/a**	**Yes**	**Yes**	
Applicant-Defined Inputs *and Illustratrative Values & Calculated Results*	**SYSTEM**					
	Configuration	Flat Plate	Flat Plate	Flat Plate	Concentrating	
	Mounting	Rack	Rack	Rack	n/a	
	Array					
	Layout					
	Modules per String	10	10	10	1	
	Strings in Parallel	4	100	6,666	250	
	Array Power (calculated)	*4,000*	*149,999*	*9,998,900*	*10,000,000*	W
	Inverters	1	1	67	63	
	Total Inverter Power (calculated)	*4,000*	*150,000*	*10,050,000*	*10,080,000*	W
	Performance					
	System Derate Factor (shading, mismatch…)	5	5	5	5	%
	System Degradation	1	1	1	1	%/year
	Tracking Type	Fixed	Fixed	1-axis	2-axis	
	Orientation					
	Tilt	18	15	0	n/a	degrees
	Azimuth	0	0	0	n/a	degrees
	Ground Reflectance	0.2	0.2	0.2	n/a	
	Module	Single-Point Efficiency Model				
	Power (calculated)	*100*	*150*	*150*	*40000*	W
	Efficiency	13.5	13.5	13.5	20	%
	Temperature Coefficient (Pmax)	-0.5	-0.5	-0.5	n/a	
	Structure	glass/cell/polymer			n/a	
	Area	0.74	1.11	1.11	200	m^2
	Inverter	Single-Point Efficiency Model				
	Power	4,000	150,000	150,000	160,000	W
	Efficiency	90.0	92.0	92.0	92.0	%
	Costs					
	Module	$400	$525	$495	$165,200	$/unit
	Inverter	$3,600	$90,000	$69,000	$73,600	$/unit
	Storage	$0	$0	$0	$0	$
	BOS (except inverter)	$2,440	$81,000	$9,700,000	$7,000,000	$
	Installation cost	$6,640	$82,500	$2,700,000	$5,500,000	$
	Indirect and other cost	$5,200	$165,000	$5,500,000	$1,100,000	$
	Total Installed Cost (calculated)	*$33,880*	*$943,500*	*$55,519,700*	*$59,536,800*	$
	Annual O and M from spreadsheet	*$625*	*$6,365*	*$188,541*	*$579,966*	$/yr
	O&M Spreadsheet Inputs					
	Routine Annual O&M	0.5	0.45	0.15	0.85	% of installed cost
	Inverter Lifetime before replace/rebuild	5	10	10	10	years
	Inverter Replacment/rebuild	100	50	50	35	% of inverter cost
	Levelized Cost of Energy (calculated)	*32*	*16*	*21*	*25*	*¢/kWh (real)*

Table 1: Input Parameters Required for SAM Model.

Program-defined inputs provided in the top of the table.

Values for applicant-defined inputs and the resulting LCOE are for illustration only.

Cost data essentially consists of two parts: first-cost and ongoing costs, such as operation and maintenance (O&M). Within SAM, first cost data are expressed simply in $'s (BOS, installation, other costs) or on a per unit basis ($'s per module or $'s per inverter). For O&M costs, the model currently accepts a single number for annual O&M costs. This cost populates the O&M cost field, and, within SAM, this number is then escalated over the life of the system at the rate of inflation. To convert all out-year O&M costs to a single number for input to SAM, an O&M spreadsheet is provided with SAM. Applicants should populate the spreadsheet with all potential O&M costs that may occur over the analysis period (30 years). Such costs could include routine O&M (e.g. periodic system inspection, module cleaning, and, for a ground-mounted system, weed control), periodic inverter rebuild or replacement, and repair or replacement of any other components that might be required during the analysis period. If the baseline system and/or module lifetime is less than thirty years, the applicant may elect to shorten the analysis period to the baseline lifetime. SAM analyses must be conducted not only for the baseline system(s), but also for systems that reflect projected improvements (2010 and 2015).

Special Cases (including BIPV and Storage) – Some systems may have added value, due, for example, to building integration. Added value that partially offsets first costs, for example elimination of conventional roofing material by the PV panels, can be reflected in reduced total BOS (reduced material) and installation (reduced labor) costs, supported by appropriate documentation.

Added value from systems that provide an ongoing benefit, such as reduced thermal losses from a building or delivery of thermal energy to the building, may also be indirectly accommodated by the model. In this case, applicants need to provide their own calculation of thermal energy savings, assuming weather conditions as described by TMY2 data for the location being analyzed. Future cost savings should be calculated based on average energy costs reported in EIA's Annual Energy Outlook 2006 reference case. This data can then be entered into the O&M spreadsheet described above for converting varying out year costs (savings) to an annual cost. Applicants in this situation may want to analyze LCOE in locations in colder climates in addition to analysis of the required Phoenix location.

If a system contains storage, the applicant should propose in a qualitative and quantitative fashion the value the storage brings to the system and the market. This could be done by considering time of use rates or increased value of renewable energy credits for having dispatchable solar power. This value, in turn, can be applied to the LCOE calculation to offset the additional cost of the storage in the final LCOE determination.

3.3 Use of the Solar Advisor Model in the Application Process.

During the application phase, applicants will use the model to calculate LCOE for their current technology and for proposed improvements, as shown in Figure 4. Applicants must provide the input noted in the system parameters box.

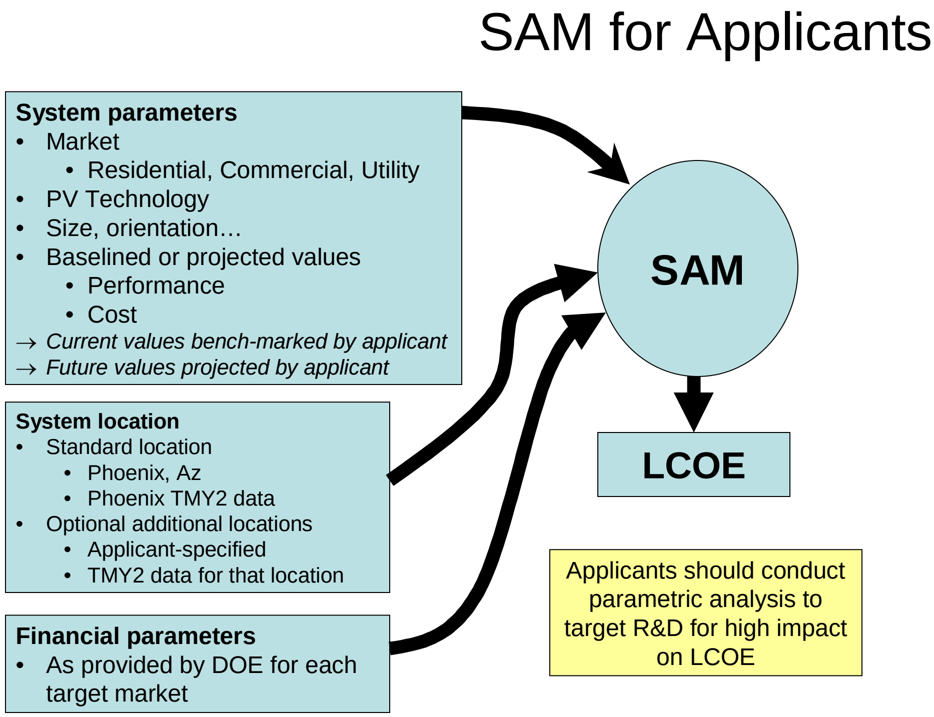

Figure 4: Depiction of SAM's use during application evaluation.

For current technology, performance and cost input parameters should come from current baseline data submitted by TPPs. Although the FOA does not establish a firm standard for baseline data, reviewers will evaluate baseline data on the explicit and implied level of validation. Examples of valid baseline data might be performance data from independent testing organizations, representative price data from bid documents for completed systems, and O&M data from currently operating systems.

Projected improvements in performance and reductions in cost must be supported in detail in the application and shall be described in terms of specific technology improvement opportunities. Based on analysis and experience, applications are expected to identify and quantify one or more sets of improvements, which, if accomplished, are sufficient to achieve SAI goals. Such paths might range from a research plan for improving module efficiency, requiring significant funding under the application, to cost reduction shown to be available from volume purchasing, with no funding required. Improvements for which the Applicant has documented no path forward cannot be assumed to be achieved. For example, if the Applicant states that installation costs must be cut in half to achieve the LCOE target, but provides no path to achieving that cost reduction, the application has not established the existence of a path to achieving the target LCOE.

3.4 SETP Modeling Working Group

Under the stipulations of FOA Part 1D (SAI TPP Partnership Collaborative Activity objectives), TPPs will be requested to participate in a modeling working group for the purpose of improving modeling capability within DOE's solar program and the solar community. This working group will also work to improve the capability and usefulness of the Solar Advisor Model, including enhancing its ability to interface with other solar models. SETP envisions an annual modeling workshop, as well as less formal meetings held periodically, but not more than quarterly.

SETP will develop an inventory of models that are currently made available to the solar community, from academic, industry, and laboratory sources. SAI recipients are required to participate in this process. Recipients and others in the community may also identify proprietary models for which they would like to develop interfaces with SAM or which they would like to validate. SETP will work with SAI recipients and the broader solar community to prioritize upgrades to SAM, interfaces between SAM and existing public and proprietary models, and the validation of SAM and other models.

4.0 Testing and Evaluation in Support of the Solar America Initiative

The test and evaluation (T&E) activities within the Solar Energy Technologies Program (SETP) will focus on collaboration and cooperation with industry to:

- develop better products through failure analysis, identification of and solutions to degradation mechanisms, and development and application of characterization methodologies to help industry develop and field reliable products;
- provide the technical basis for barrier removal; and
- obtain data that quantify performance and reliability improvements within the industry and the SETP.

A schematic of these test and evaluation activities is provided in Figure 5. The T&E staff currently obtains “hardware” from a variety of sources (U.S. and global manufacturers, system integrators, and university/internal researchers) and will obtain both prototype and commercial hardware from TPP teams. The term “hardware” refers to systems, components, devices, materials, or manufacturing processes made available for evaluation, including field evaluations of newly installed or aged systems. SETP researchers work collaboratively with industry engineers to improve and understand their systems, modules, devices, materials, or manufacturing processes through tests, measurements, and characterization activities.

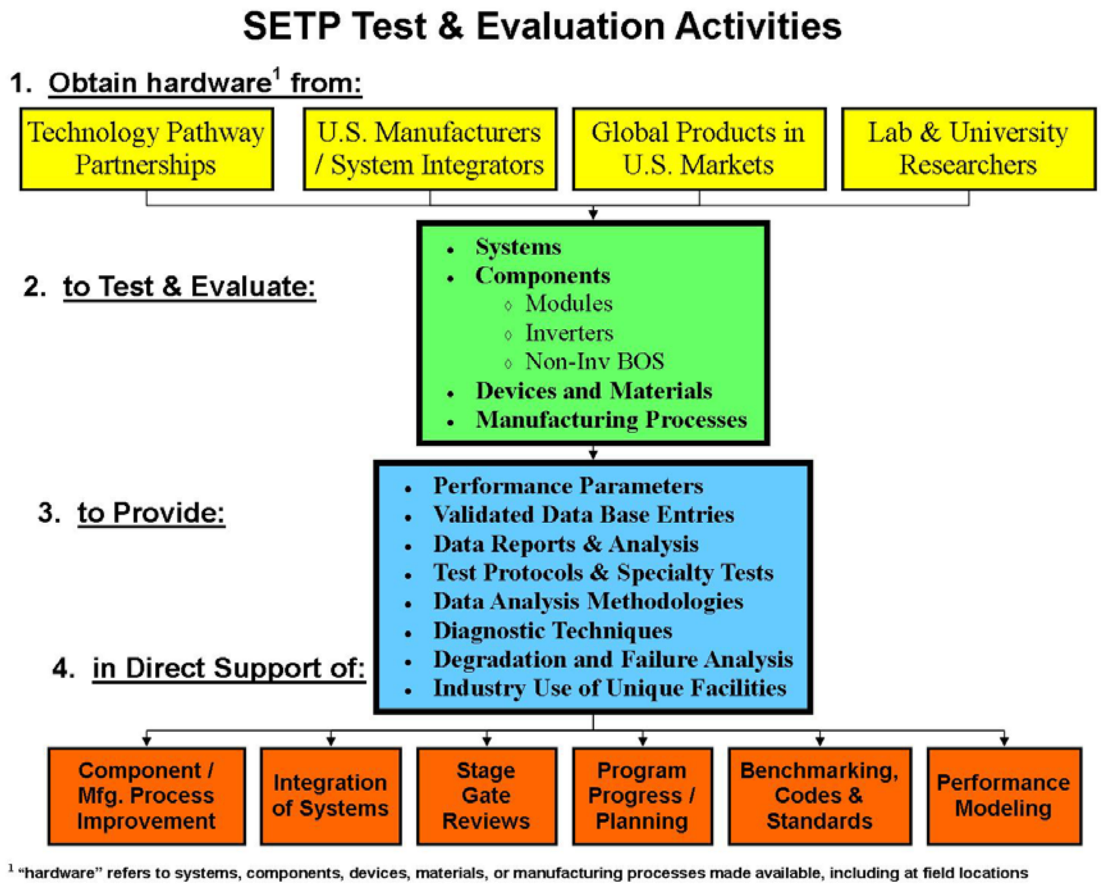

Figure 5. Test and Evaluation Activities in the Solar Energy Technologies Program in Support of the SAI.

These evaluations produce performance parameters, validated database entries, data reports and analyses, test protocols, and data analysis methodologies. In addition, diagnostic techniques for use in product improvement or process understanding are developed, often as part of extensive degradation and failure evaluations. Similarly, specialty measurements can be performed to support evaluation of new system or component concepts; often the insights gained in these evaluations lead to improvements in existing test protocols or may lead to new ones. Finally, access is provided for direct industry use of "one of a kind" test facilities, such as the new Science and Technology Facility at NREL or the PV Systems Optimization Lab at Sandia.

As indicated in the figure, these results are used for a variety of purposes. Some are used collaboratively with industry to improve components, manufacturing processes, and integration of systems. Some results support stage gate evaluations, benchmarking, codes and standards development, and performance modeling. Results are also valuable in planning and evaluating SETP technical activities.

The TPPs can therefore benefit substantially from the use of these resources to provide data on pre-commercial and commercial products or samples. Early utilization of these capabilities will likely result in clearer understanding of system or component performance so that further improvements can be made. The DOE will also utilize some of the results, namely those on specimens submitted specifically for evaluation against previously-established gate criteria, in the Stage Gate (accountability) evaluations required to assure that TPP progress is independently validated.

Supporting these SETP test and evaluation efforts are the personnel, processes, capabilities, equipment, and facilities at the National Laboratories (National Center for Photovoltaics: National Renewable Energy Laboratory and Sandia National Laboratories), Environmental Health and Safety efforts of Brookhaven National Laboratory, and the Solar Energy Technology Program's Regional Experiment Stations (SW, Southwest Technology Development Institute and SE, Florida Solar Energy Center). This work is funded under the SETP "core" program and is provided to complement the capabilities of many private entities and standards & codes organizations that also support the PV industry. When used to validate deliverables, test and evaluation results will be fully documented for integrity and transparency, with a formal protocol for product delivery, testing, and dissemination of results. As is currently the case in SETP activities, proprietary data will be handled using secure protocols negotiated with the TPP teams prior to award.

4.1 Current SETP Test and Evaluation Capabilities

An inventory of the test and evaluation capabilities directly supporting the SETP at the National Laboratories (National Center for Photovoltaics – NREL, Sandia, and Environmental Health and Safety activities at Brookhaven) and the Southwest and Southeast Regional Experiment Stations, is located in the Appendix.

This list of capabilities highlights the availability of extensive laboratories and personnel for a wide variety of measurements. Indoor and outdoor facilities are noted along with off-site measurement capabilities. Systems, components, and devices can be assessed for all of the photovoltaic technologies. A wide variety of environments can be simulated from nominal (standardized) operating conditions to accelerated aging conditions, from grid-interactive to stand-alone, and from dry to humid conditions. Systems tests can be conducted to assure functionality of all components and to establish performance parameters. Durability, reliability, and high stress conditions can be evaluated using both standard and specialty test protocols. Manufacturing process steps can be replicated and diagnostic measurement techniques evaluated. Many diagnostic capabilities support and enhance the understanding of these measurements; these include (though the list is too extensive to effectively summarize) an extensive array of equipment for making spectroscopy measurements, performing surface characterization, measuring spectral response, assessing chemical composition, and assessing failure and degradation mechanisms.

It is recognized that it will be exceedingly difficult for applicants to identify in advance all the specific diagnostic capabilities needed to support their partnership. Collaborative R&D relationships with the SETP routinely provide the opportunity to apply specific measurement techniques to assess the specific concerns that become evident during product development. Assuring traceability and extensive calibration of test equipment is a routine part of operations for QA/QC activities along with following established test protocols and carefully documenting all test techniques, results, and analyses. It should also be noted that while the SETP actively supports the development of certification protocols for PV products and practitioners, **product certification testing will not be done by the SETP staff; TPPs must obtain any desired commercial product certifications from commercial sources.**

4.2 Test & Evaluation Requirements in FOA Applications

Applicants responding to the FOA are required to describe the T&E support needed to support their proposed activities. This includes the types of testing needed, hardware required, and the anticipated duration. This description of testing needs in the application will include the support needed for both product/process improvement as well as for validation of their deliverables. Detailed planning and scheduling will be done with each of the awardees to assure timely availability of the needed Test and Evaluation resources and capabilities to help assure success of the Solar America Initiative. In addition, Technology Pathway Partnerships will participate in the development of test and evaluation protocols where none exist or in the improvement of existing protocols.

As an example of the types of collaborative testing support that can be valuable for improving products developed within the Technology Pathway Partnerships of the SAI, consider the extensive support frequently provided for large utility or commercial-scale installations:

- Baseline performance characterization of a sample (generally, about 5) of pre-qualified individual modules (already passed the IEC, IEEE, and UL qualification tests), day long field performance characterization of multiple module-strings in the PV array using the test protocol to obtain array performance parameters, measurements and associated statistical evaluation of open-circuit voltage for all module-strings in the array, verification of code compliance and grounding method, month long measurement of inverter dc input and ac output to obtain in-situ inverter performance parameters.
- Array and inverter performance parameters along with associated models are used to calculate expected ac energy production for comparison with measured production.
- Continuous system performance monitoring will identify easily detectable system performance issues, and detailed evaluation of module, array, and inverter characteristics performed on a periodic basis (annual) will be used to identify more subtle reliability issues and/or degradation rates.
- Additional measurements provided include spectral response of representative cells, and the fabrication and calibration of reference cells with the same mechanical and optical characteristics as the modules.
- If significant performance or reliability issues are noted, an extensive array of diagnostic techniques is available (e.g., material evaluations, microscopy, spectroscopy, dark IV analysis, infrared imaging, metallurgical analysis, ultrasonic imaging, etc.).
- Test and evaluation protocols for residential scale systems are much the same as for commercial scale systems with the exception that more testing may be performed in a laboratory environment using specified modules, inverter, wiring, and other BOS components.

It is also foreseen that some amount of T&E will be required during the early stages of the TPPs (perhaps during the first year) to establish and verify baselines for the technology developments to be conducted. If an Applicant wishes to utilize the capabilities of the SETP laboratories to conduct such baseline tests, this must be stated and planned as part of the application. Note that no T&E will be conducted to verify data in applications prior to selection of Recipients.

For information about these test capabilities, applicants may contact points of contact at the SETP-funded National Laboratories. The Points of Contact are:

NREL:	Dr. Harin Ullal, saicontact@nrel.gov 303-384-7799
Sandia:	Dr. Jeffrey Nelson, jsnelso@sandia.gov, 505-284-1715
Brookhaven:	Dr. Vasilis Fthenakis vmf@bnl.gov, 631 344-2830

Points of contact for the Southeast and Southwest Regional Experiment Stations are:

SERES:	Mr. Kevin Lynn, klynn@fsec.ucf.edu, 321-638-1440
SWRES:	Mr. Andy Rosenthal, arosenth@nmsu.edu, 505-646-1323

Should a TPP project require unique test facilities or protocols not presently available at the SETP-funded Laboratories or RES's, funding for these TPP-unique test & evaluation functions should be included in the application budget and will be counted against the TPP project cost and award ceiling. For new types of tests, Applicants will be required to coordinate with laboratory Points of Contact to determine whether these new requirements will be accommodated within the SETP "core" program or whether they must be funded from the TPP application budget.

4.3 Coordination and Communication after Award

In the time period following the review of applications, when awards will be negotiated, SETP and laboratory staff will work with successful Applicants to further define the details and expectations of T&E activities over the course of Phase 1 of SAI. This further refinement will assist overall program planning efforts in helping to assure: the timely development of needed protocols, procedures, potentially including the set-up of new laboratory equipment or evaluation capabilities; and to inform budgeting for laboratory support of TPPs. Given that this is a technology development funding opportunity spanning three years, some amount of flexibility will be built into these schedules, allowing for schedule variation during project implementation.

To facilitate the further development of test and evaluations plans, the above laboratory points of contact will continue their roles as coordinators of these efforts. They will identify appropriate lab, RES, and other personnel who will then coordinate directly with the TPP technologists to plan collaborative test and evaluation activities.

5.0 Conclusion / Additional Questions

This reference document has been provided to Applicants with information that will be of direct use in the development of applications under this FOA. This document is also intended to provide a contextual basis for the requirements stated in the FOA, with the intent to greater facilitate the development of clear, concise applications that directly address DOE program goals. **Applicants with further questions are advised to communicate with the DOE contracting officer, or with the laboratory POCs through the contact information provided in this document and on the DOE Industry Interactive Procurement System (IIPS).**

APPENDIX:
DOE Solar America Initiative
Solar Energy Technologies Program (SETP) PV Testing and Evaluation Capabilities

National Renewable Energy Laboratory, Sandia National Laboratories, Brookhaven National Laboratory, Southeast and Southwest Regional Experiment Stations

For information about these capabilities, applicants may contact points of contact at the SETP-funded National Laboratories. The points of contact are:

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Brookhaven:	Dr. Vasilis Fthenakis	vmf@bnl.gov	631-344-2830

Points of contact for the Southeast and Southwest Regional Experiment Stations are:

SERES:	Mr. Kevin Lynn	klynn@fsec.ucf.edu	321-638-1440
SWRES:	Mr. Andy Rosenthal	arosenth@nmsu.edu	505-646-1323

Capabilities include, but are not limited, to the following:

PV Testing and Evaluation (T&E) Capabilities Inventory SETP (NREL, Sandia, SERES, & SWRES)

SYSTEMS – T&E Capabilities

Descriptor	Description of capability (including Web links)	Specific tests / measurements / characterizations
NREL Small Systems Testing	Real-time testing of small grid-connected PV systems. IEEE Standard 1526 small-standalone system testing. www.nrel.gov/ncpv/performance_reliability	System real-time performance, system degradation rates, changes to modules under actual use conditions.
NREL Solar Radiation Research Laboratory Broadband and Spectral Radiometry, Metrology, and Resource Data Characterization	Traceability of radiometric measurements to World Radiometric Reference through cavity radiometer (for cell and module measurements). Broadband and spectral irradiance characterization. www.nrel.gov/srrl www.nrel.gov/midc	Radiometer calibration and measurement uncertainty, with traceability to world standards for cell and module performance measurements. Spectral radiation characterization for traceability, measurement uncertainty, and reporting for cells and modules with respect to standard spectra. Spectral characterization of flash solar simulators. Access to NREL and remote testing site solar and meteorological near-real-time and archived data streams. These capabilities also apply to modules and cells.
NREL Renewable Resource Data Center	Access to national and international solar radiation databases, data sets, and measurement activities. Broadband, spectral, and circumsolar	Interpretation and applications of 30-year National Solar Radiation Data Base and other measurement data sets (NASA Surface Solar Energy site, WMO World Radiation Data Center).

Solar Resource Characterization - Broadband and Spectral Radiative Transfer Modeling and Irradiance Characterization	measurement data sets. Expertise and operational capability in radiative transfer codes. Development, application, and interpretation of resource data for system testing and simulation. http://rredc.nrel.gov www.nrel.gov/midc/srrl_bms www.nrel.gov/gis/solar.html	Development, validation, and evaluation of solar resource spectral models for device and system design, deployment, and testing community. Assistance for operation and interpretation of PVWatts solar calculators and on-line U.S. National Solar Radiation Atlases. Interactive Solar Resource Geographical Information Systems Maps and downloadable data. These capabilities also apply to modules and cells.
Sandia PV System Optimization Lab	Fully instrumented and calibrated facility for evaluating performance and reliability of residential-scale inverter/array combinations. 12 configurable 3-kW PV arrays. www.sandia.gov/detl www.sandia.gov/pv	Continuous measurements and analysis of all system dc and ac performance variables in addition to associated solar resource and weather parameters. Determination of array and inverter performance parameters for energy modeling using Sandia protocols. Test and analysis of long-term aging characteristics of arrays and inverters. Evaluation of system performance monitoring hardware.
Sandia Field Performance Testing	Comprehensive field testing of large PV systems and components using portable instrumentation. www.sandia.gov/detl www.sandia.gov/pv	Performance characterization and diagnostic testing of utility-scale PV arrays at source-circuit level (< 25 kW) using portable curve tracers. In-situ inverter performance characterization using ac and dc sensors with datalogger. Determination of array and inverter energy modeling parameters using Sandia test protocols. Thermal (IR) imaging surveys.
SERES PV System Performance Monitoring	Capability for remote monitoring and archive of performance data from a large number of installed PV systems. www.sitepower.org	Measurement: Involves installation of data acquisition systems (DAS) to monitor sunlight, dc and ac voltage and current and power. Reporting: Consistent with IEC 61724.
SERES Small Systems Test Facility	Designed to test the performance of small stand-alone (off-grid) PV systems.	Tested using DAS systems according to IEEE 1526 standard.
SWRES PV System Field Test/Evaluation	Test and evaluation of field installed prototype and production PV systems and components. www.nmsu.edu/~tdi/Photovoltaics/PV-Energy.html	Array and system ratings. System acceptance testing (validation of dc and ac specifications). System code compliance evaluation (array, inverter BOS, workmanship). IV measurements (arrays, strings, modules). Inverter evaluations (power quality, conversion efficiency, transitions). Monitoring and data collection for PVUSA PTC-rating (30-day test). Development of hardware and software for system testing and monitoring. Testing for UL and NEC code compliance.
SWRES Long-Term Hot-Dry Outdoor Exposure Testing of Systems and Components	Exposure testing and monitoring of modules, arrays, inverters, and BOS components. www.nmsu.edu/~tdi/Photovoltaics/PV-Energy.html	Exposure testing of PV modules (annual radiation >2,300 kWh/m^2, two-axis trackers, automatic IV acquisition). Inverter testing (cycling, high temperature operation, configurable dc inputs). BOS test and evaluations (batteries, charge controls).

MODULES & ARRAYS – T&E Capabilities		
Descriptor	**Description of capability (including Web links)**	**Specific tests / measurements / characterizations**
BNL EH&S Research Center	Lab-scale recycling of metals and glass from PV modules. Assisting with EH&S reviews in PV module manufacturing facilities. Estimating energy payback and CO_2 emissions from the life-cycle of PV systems. Defining the environmental profile of PV and comparison with other energy technologies. Atmospheric dispersion modeling. www.pv.bnl.gov	Hydrometallurgical separations of Cd from Te and Se from In and Zn in CdTe and CIGS PV modules. Inductively Coupled Plasma Analysis (ICP) of elements in solutions. XRF and XRD analyses of solid samples. Lifecycle analysis of PV modules and BOS. Using various atmospheric dispersion models to predict hazard zones.
NREL Indoor Module Stress Testing	Standard and customized stress testing of PV modules. www.nrel.gov/ncpv/performance_reliability	**IEC 61215/61730 tests:** dielectric withstand, ground continuity, accessibility, wet leakage current, UV preconditioning, damp heat, thermal cycling, hot spot endurance, bypass diode thermal test, hail test, mechanical load, humidity-freeze, robustness of terminations, reverse current test, JBox securement **Custom tests:** light soaking in environmental chambers, longer, special, or combined chamber sequences.
NREL High Voltage Test Bed	Outdoor stressing of PV modules and arrays at system voltages. www.nrel.gov/ncpv/performance_reliability	Array/module leakage currents to ground, real-time performance.
NREL Performance & Energy Ratings Test Bed	45 module channels provided by Raydec Multitracer electronic loads. www.nrel.gov/ncpv/performance_reliability	Maximum power point tracking loading, temperature & irradiance measurements, periodic I-V curves, real-time performance, Performance Test Conditions (PTC) ratings, temperature coefficients, module degradation rates.
NREL Outdoor Accelerated Test System	Two-axis active solar tracking with mirror light enhancement provides up to 2.5x concentration in two test planes with active air cooling. www.nrel.gov/ncpv/performance_reliability	Accelerated module weathering, module degradation rates.
NREL Outdoor Performance Measurements	Outdoor module exposure racks. www.nrel.gov/ncpv/performance_reliability	Non-real-time performance monitoring, module degradation rates. **IEC 61215/61730 tests:** temperature test, hot spot endurance, outdoor exposure.
NREL Module Efficiency Measurements	Light and dark I-V, spectral responsivity versus voltage and light. Any size flat-plate module outdoors. www.nrel.gov/measurements/device.html	Outdoors and continuous light test-beds (±300 V, ±60 A to micro A and micro V). Spire 240 A for pulsed solar simulator (20 A, 100 V max, 2-ft by 4-ft or smaller modules). ISO 17025 accredited.

NREL Module Laser Scanner	Module laser scanner using rastered HeNe laser beam, and light chopper to produce response maps of modules as a function of bias voltage. www.nrel.gov/measurements/electro_op.html	Providing photo-response maps of modules to reveal shunting regions and other loss mechanisms. Tool for reliability and failure analysis complements infrared camera.
NREL Concentrator Module Performance & Energy Ratings Test Bed	Concentrator module performance and energy ratings measurements	Unattended I-V on 2-axis tracker for 1 to 10 prototype concentrator cells or modules, with periodic spectra, 10-min typical interval, and full meteorological data, 100 V, 20 A max, micro A, micro V min. Determining Performance Test Conditions (PTC) ratings, temperature coefficients, module degradation rates.
Sandia PV Module Evaluation Lab	Comprehensive electrical, thermal, optical characterization of module and small array performance. Diagnostic evaluation of field failures and production anomalies. www.sandia.gov/pv	Outdoor performance of modules/arrays to 1,800 W using ASTM procedures and 2-axis tracker. Temperature coefficients, NOCT and PTC operating temperatures. Solar spectral and angle-of-incidence characteristics. Cell shading and hot-spot testing. Energy modeling parameters using Sandia test protocol. Baseline and periodic retesting for field or accelerated aging tests. Dark IV analysis for modules and bypass diodes. Diagnostic analyses using UV, thermal (IR), and ultrasonic imaging. Destructive tests: encapsulant adhesion, interface chemistry, glass transmittance, solder-bond cross-sections.
SERES PV Module Performance Testing	Tests to measure the performance of PV modules at standard reporting conditions. www.fsec.ucf.edu/pvt/buyinstallpv/moduletesting.htm	Indoor module performance test based on ASTM 1036 using Spire Sun Simulator 660. Outdoor Performance Test: FSEC Standard based on ASTM 1036 and Sandia protocol with Daystar 1200 curve tracer. Accreditations: • ISO 17025 through AALA • Powermark Accreditation
SERES Long-Term Module Testing	Designed to test the long-term performance and reliability of commercial PV modules. www.fsec.ucf.edu/pvt/Projects/seres	Modules mounted in Florida's hot, humid climate with resistive load. Exposure with high-voltage bias also available. Monthly IV curves to identify power degradation and failure mechanisms.

INVERTERS & OTHER BOS – T&E Capabilities		
Descriptor	**Description of capability (including Web links)**	**Specific tests / measurements / characterizations**
Sandia Distributed Energy Technologies Lab	Comprehensive characterization and analysis of power conversion and control equipment for grid-interactive, stand-alone, and hybrid systems with options to use either PV or simulated dc and ac energy sources (60-kW PV, generators, 800 kWh battery storage). www.sandia.gov/detl www.sandia.gov/pv	Inverter characterizations: Efficiency vs. loads (resistive, inductive, capacitive, non-linear, and tuned). Peak power rating per Sandia/CEC protocol. Power quality (total harmonic distortion) per IEEE 519. Thermal (IR) imaging, RF emissions and susceptibility per FCC part 15B. Surge susceptibility per ANSI C62.41. Utility compatibility (anti-islanding, surges, sags) per UL1741 and IEEE 1547. Lightning and switching transient simulation. Utility-specified voltage waveform interfaces. Thermal chamber for extreme temperatures. Long-term operating (aging) with failure diagnostics.
Sandia Battery Test and Analysis Lab	Performance and failure analysis of batteries used in off-grid PV systems www.sandia.gov/detl www.sandia.gov/pv	Characterization of battery capacity vs. voltage, specific gravity, hydrogen generation, charging characteristics, discharge characteristics as function of discharge rate. Charge controller testing. System tests with programmable array simulator.
SERES Long-term Inverter Testing	Testing of the long-term performance and reliability of inverters. www.fsec.ucf.edu/pvt/Projects/inverter/index.htm	Measurement: Similar DAS to monitor long-term performance of systems and inverters at FSEC. Relative comparisons of inverter technologies for same test conditions.
SWRES Long-Term Hot-Dry Inverter Testing	Exposure testing and monitoring of long-term inverter performance. www.nmsu.edu/~tdi/Photovoltaics/PV-Energy.html	Fully instrumented long-term inverter testing (cycling, high-temperature operation, configurable dc inputs) to assess reliability and failure mechanisms.
SERES Battery Testing	Test the performance characteristics of batteries for PV systems. www.fsec.ucf.edu/pvt/Projects/seres	Power supplies and resistors used to cycle batteries, simulate array.

DEVICES & CELLS – T&E Capabilities		
Descriptor	**Description of capability (including Web links)**	**Specific tests / measurements / characterizations**
NREL Cell Efficiency Measurements	Measure performance of PV cells and modules with respect to standard reporting conditions. www.nrel.gov/measurements/device.html	Light and dark current-voltage (I-V), spectral responsivity versus voltage and light. All PV cell technologies with minimum uncertainty. Spectrally adjustable simulator, temperature, pre-measurement, and bias-rate issues addressed.
NREL Primary Reference Cell Calibration Facility	Rigorous calibration of reference cells used by industry and labs with traceability to recognized standards. www.nrel.gov/measurements/device.html	Four cells at a time under direct-beam light with cavity radiometer and spectral radiometer. Follows ASTM E1125. ISO 17025 accredited.
NREL Multiple Cell Environmental Stress Testing	I-V characterization of multiple cells with controlled atmosphere (inert, or air), light, and temperature levels.	CdTe/CIGS device fabrication capabilities. Study of devices, contacts, and interconnects under controlled levels of environmental stress (light, bias, humidity, temperature).
NREL Concentrator Cell Efficiency Measurements	Continuous and pulsed light sources for concentrator cell efficiency with respect to reference condition linearity not assumed. Partial spectral adjustment, if required. www.nrel.gov/measurements/device.html	Determining efficiency with respect to reference conditions, performance vs. concentration and temperature, ohmic contacts, tunnel diode analysis. Continuous xenon or tungsten light, 0.01 to 100 suns, and dark I-V. Light I-V, 1 to 2,000 suns (mA to 50 A).
Sandia PV Device Measurement Lab	Standardized cell performance and optical measurements, failure diagnostics, calibration of reference cells and sensors. www.sandia.gov/pv	Performance using ASTM procedures for one-sun and concentration to 1,000X. Temperature coefficients, dark IV analysis forward and reverse bias. Absolute spectral response, internal quantum efficiency (300 to 2,400 nm). 2-D LBIC scans (high resolution at 4 laser wavelengths or low resolution at any wavelength). Spectral reflectance/transmittance.

MODULE & CELL FAILURE ANALYSIS, MATERIALS, & DIAGNOSTICS – T&E Capabilities		
Descriptor	**Description of capability (including Web links)**	**Specific tests / measurements / characterizations**
NREL Infrared Camera, Cell and Module shunt diagnostics	(1) 320 X 256 FPA InSb, 0.2°C NEDT, (2) 320 X 256 FPA (Pt):Si, 1.0°C NEDT, portable, (3) Lock-in shunt measurement technique. www.nrel.gov/ncpv/performance_reliability	Hot-spot diagnostics. Individual cell shunt values in a series-connected module.
NREL Packaging Materials Testing Rheometer, Instron Pull Tester, and Mocon WVTR Systems, Laminator, NREL Damp Heat and a CI-4000	Sample preparation and mechanical properties testing of packaging materials, pull-strengths of interfaces, and water vapor transmission rates of backsheets and encapsulants. www.nrel.gov/ncpv/performance_reliability	Modulus (T, frequency dependencies). Shear, butt, and peel strengths up to 200 °C. WVTR to 100% rh and 85°C. Laminator samples up to 20 in x 20 in with programmable T-profile. Controlled humidity, T, and illumination control for weathering exposure.
NREL Silicon Materials and Devices	Evaluations of cell production and fabrication technologies. www.nrel.gov/ncpv/pvmenu.cgi?site=ncpv&idx=1&body=world.html	Czochralski crystal growth and wafer preparation, including ingot growth, slicing, lapping and polishing for determination of feedstock material quality in producing quality wafers and testing crucible materials. Fabrication and test of diffused junction and heterojunction solar cells; determination of wafer (or feedstock) quality in producing PV cells. SUNS-Voc testing of solar cells; contactless determination of I-V and efficiency potential of junction PV devices. Spreading resistance measurement; determination of doping profiles in wafer Si samples. Radio-frequency and Microwave Photoconductive Decay lifetime measurement; determine silicon material electronic quality for solar cell devices. Transient capacitance decay, photocapacitance and drive level measurements from 90-420 K; measurement of defect densities and trap depths in PV materials. Hall, Seebeck, Nernst and Resistivity measurements from 30-350 K; determination of key transport coefficients including effective mass, by method of 4 coefficients. Light-soaking station up to 30 x 30 cm^2 using metal-halogen source; determination of stability of a-Si and thin-Si materials and devices. Light-soaking station up to 20 x 20 cm^2 using ELH source; determination of stability of a-Si and thin-Si materials and devices. Combinatorial transient conductivity measurement with automated probe transport; determine resistivity

		and I-V of combinatorial arrays of materials and device samples on 5 x 5 cm^2 platforms. Constant photoconductivity method determination of absorption constants vs. wavelength down to 10^2 cm^{-2}; determine thin film subgap defect densities. Rapid (< 1 sec) determination of reflectance and transmission from 200 – 1,000 nm; determine optical gaps, optical constants and thickness of thin film materials.
NREL High Performance and III-V Solar Cells	Systems for measuring lattice properties of epitaxial layers and quantum efficiency/reflectivity of solar cells with LED bias light, yielding internal quantum efficiency of series-connected, multijunction solar cells.	Double-crystal x-ray diffractometer to measure lattice constants and strain relaxation in epitaxially grown layers; rocking mode x-ray diffraction and reciprocal space mapping. Rapid measurement of light I-V curves under variable spectra; individual junction characterization.
NREL Combinatorial High-Throughput Tools	Techniques for measuring: • Simultaneous reflection transmission • Conductivity mapping • Spectroscopy • X-ray structure.	Simultaneous Reflection Transmission (0.2-2.5 µm) - rapid position sensitive scanning R/T system for optical characterization; reflection and transmission coupled with modeling to measure optical properties of materials as a function of position. Conductivity Mapping - 4- probe conductivity mapping system; maps conductivity and is linked to the optical system above. Infrared spectroscopy - mapping infrared adsorption or reflections out to > 20 µm; data and positioning are correlated with the tools above and can be used to determine the plasma edge etc. Micro-Raman spectroscopy - 3 wavelength scanning micro-Raman capability; structural analysis indexes with the techniques above and Raman at three widely spaced wavelengths. X-Ray Structure Mapping - ToolBruker Axis 2D x-ray system capable of structural mapping and variable temp XRD; XRD mapping of phase information also indexed to other tools.
NREL Thin Films Research	Instrument systems for optical defect analysis, XRD analysis, Raman spectroscopy, surface area measurement, NMR, ESR, elemental analysis, thermal, corrosion, and electrical property measurements	Optical Defect Analysis - Optical Imaging tools for defect analysis; defects and corrosion analysis to both image and analyzed defects size and distribution. XRD analysis - Scintag XRD systems for powder pattern and single crystal structure determination. Raman Spectroscopy - Multiple wavelength, automated Raman capability. BET/scattering surface area measurements - surface area measurement using N2 adsorption or laser light scattering. NMR - Multi-nucleus solid state NMR capability. ESR - electron spin resonance for solid state materials; for relatively non-conductive materials and semiconductors. ICP elemental analysis – Solution-based chemical analysis for bulk and trace elements materials dissolved in acid media. TGA/DTA - Systems for thermal gravimetric and differential thermal analysis; sequential or simultaneous tests on small samples.

		Electrochemical/corrosion measurements, multichannel characterization system capable of near combinatorial application; multiple channel PAR and Arbin electrochemical systems computerized and three electrode; I-V, corrosion potential, C-V and impedance measurement. Varian spectrophotometer - Ultraviolet, visible and near-infra-red spectrophotometer; measuring reflectance, transmittance and absorbance.
NREL Secondary-Ion Mass Spectrometers (SIMS) Laboratory	SIMS techniques used to analyze the surface of a material or determine the depth distribution of elements as the primary ion beam sputters through a material. www.nrel.gov/measurements	Cameca IMS-5F and Cameca IMS-3F (SIMS): Full Periodic Table analysis of trace elements, dopants and contaminants, multiple-source depth profiling, mass scans, secondary-ion imaging, isotopic information, ppm–ppb atomic sensitivity. ION-TOF IV Time-of-Flight SIMS: Surface molecular and elemental analysis, mass range to >10,000 amu, full Periodic Table, multiple-source depth profiling, ppm–ppb surface sensitivity.
NREL Analytical Microscopy Laboratories	Analytical tools and imaging to characterize materials and devices for their topographical, defect, structural, compositional, electrical, and luminescent properties. Novel techniques for analyses and basic materials studies. www.nrel.gov/measurements	Phillips CM30 Transmission Electron Microscope, FEI F20 Field-Emission Scanning Transmission Electron Microscope: analyzing crystallinity, defect properties, microstructure and chemical properties. Analytical probe size down to 2 Å. Resolution down to 1.4 Å.. JEOL 5800 Analytical Scanning Electron Microscope, and JEOL 6320F Field-Emission Scanning Electron Microscope: investigating morphology, surface structure, crystallographic mapping (EBSD), chemical composition (EDS), microelectrical properties (EBIC) and luminescent properties (cathodoluminescence). Electron-Probe Microanalysis (EPMA), JEOL JXA 8900–with EDS and WDS spectrometers: Full capabilities of quantitative compositional measurements down to 0.5 atomic percent. FEI Nova 200 Dual-Beam Focused Ion Beam Work Station: Preparing site-specific samples for TEM and SEM examination. Fabricating nanostructures and nano-machining. Veeco Dimension 3100 Atomic Force Microscopes (AFM); Omicron VT-Scanning Tunneling Microscope (STM)/AFM: Nanoscale characterization of sample morphology and electrical properties, including close-loop tip positioning. Conductive-AFM, Scanning Kelvin probe microscopy, scanning capacitance microscopy.
NREL Electro-Optical Laboratory	Electrical and optical experimental techniques to examine many fundamental properties of materials. Primary techniques and capabilities include: • Photoluminescence spectroscopy • Minority-carrier lifetime spectroscopy • Fourier-transform infrared and Raman spectroscopy • Spectroscopic ellipsometry	Photoluminescence Spectroscopy (PL, FT-PL): Determining bandgap, impurity levels, recombination mechanisms, defect identification. Minority-Carrier Lifetime Spectroscopy (TRPL, RCPCD, and others): Determining minority-carrier lifetime, dominant recombination mechanisms. Fourier-Transform Infrared and Raman Spectroscopy (FTIR, FT-Raman): Providing information on composition, impurity concentration, local environment, carrier concentration. Spectroscopic Ellipsometry (SE, VASE, and RTSE):

	• Capacitance techniques • Scanning defect mapping. www.nrel.gov/measurements	Determining film thickness, crystallinity, composition, roughness, temperature, optical, electronic properties. Capacitance Spectroscopy (C-V, DLTS): Determining free-carrier concentration, defect-state parameters. Scanning Defect Mapping and Reflectance Spectroscopy (PVScan, PV Reflectometer): Determining dislocations, grain boundaries, photovoltaic response, minority-carrier diffusion length, surface roughness, other device properties. Computational Modeling: Simulating electro-optical experiments and solar cell devices. Technique Development: Creating new experimental techniques and in-line diagnostic for PV industry.
NREL Surface Analysis Laboratory	Surface analysis to determine the chemical, elemental, and molecular composition of material surfaces and interfaces. www.nrel.gov/measurements	Physical Electronics PHI 670 Field-Emission Scanning Auger Microscopy (FE-SAM): Determining surface elemental composition Li–U, depth-profile analysis, high spatial resolution elemental mapping, line-scan analysis. Physical Electronics PHI 5600 X-Ray and Ultraviolet Photoelectron Spectroscopy (XPS/UPS): Determining chemical state, surface elemental composition Li–U, angle-resolved measurements, work-function measurements, surface electronic structure. Surface Analysis Cluster Tool—integrated analysis, growth, and processing platform that combines FE-AES, XPS/UPS, thin-film deposition chamber equipped with *in-situ* characterization, inert atmosphere wet-processing station, ultra-high-vacuum transfer between all systems. Full capabilities include thin-film reaction kinetics, *in-situ* growth capabilities, controlled sample heating, desorption studies by thermal desorption mass spectrometry, *in-situ* chemical processing under controlled ambient.